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Reply to Comment on 'Light-Induced Drift of Quantum-Confined Electrons in Semiconductor Heterostructures' by A. A. Grinberg and S. Luryi

by

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The effect of light-induced drift of quantum-confined electrons in semiconductor heterostructures is discussed.

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Physical Review Letters: Reply to Comment by A. A. Grinberg and S. Luryi on Phys. Rev. Lett. 65, 3433 (1990)

Stockman, Pandey, and George's Reply: In the first paragraph of their Comment,[1] Grinberg and Luryi stated that the effect of light-induced drift (LID) of quantum-confined electrons described in Ref. 2 "is identical to the photon-drag effect (PDE) observed experimentally[3] ... and discussed in detail theoretically [4,5]", adding that, in their opinion, "LID can be viewed as a special case of PDE". Here we will address a scientific question about the identity of the effects described in Refs. 2 and 4,5, and, generally, the relation between LID and PDE.

In Ref. 1 any photocurrent in bulk, whose existence is due to photon momentum **k**, is called PDE. But, in isotropic or centrosymmetric media at rest, a photocurrent is always directed along **k**. Hence, in the definition of Ref. 1, PDE is simply a synonym of a photocurrent or photogalvanic effect. In contrast to this, LID of particles, as originally suggested[7], is a well-defined effect which takes place if: (i) the particles have different internal states, (ii) the dispersion law of the particles does not depend (or weakly depends) on the internal state (parallel bands for electrons), and (iii) their translational (momentum) relaxation depends on the internal state. One of the distinctive features of LID is that the particle flux is an *antisymmetric* function of the light frequency detuning from the absorption line, and only "dependence of the flux direction on the photon energy"[1] does not suffice. Clearly, the resonant PDE in bulk Ge, which is referred to in Ref. 1, does not confirm to the above requirements and is not LID.

Originally, the idea of effects described in Ref. 2 and Refs. 4,5 has been suggested by Dykhne, Roslyakov and Starostin[6] as an exact counterpart of LID in gases[7]. However, in Ref. 6 no quantitative description of the effect is given. In our paper,[2] we refer to Ref. 6 and give a qualitative and quantitative theory. The effects considered in Refs. 2 and Refs. 4,5 are, in fact, very close to the original suggestion of Ref. 6 and, consequently, to each other, but not identical. The main distinction between them is that in Ref. 2 the effect is based on the difference of the momentum relaxation rates ν_m and ν_n in different subbands m and n, while in Refs. 4 and 5 the effect, as it is quantitatively described, is based on the difference in the lifetimes. In our case[2] the rate difference $\nu_m - \nu_n$ originates from the scattering of electrons by impurities, whose density should be nonuniform across the well, and state-dependent wave function of electrons. In Refs. 4 and 5, the difference

of lifetimes is due to the optical-phonon emission in the upper subband.

We have considered[2] optically linear and nonlinear effects, and also have found the temperature dependence and the difference in the relaxation rates. From all these results, only the linear effect is studied in Refs. 4 and 5. In these works, no distinction is made between population-, polarization- and momentum-relaxation rates, and the photocurrent j is, in our opinion, found incorrectly. For instance, in Ref. 4 the current in its spectral maximum is $j \propto (\tau_m - \tau_n)/\gamma$ [see Eqs. (7) and (8) in Ref. 4], with $\gamma = \frac{1}{2}\left(\tau_m^{-1} + \tau_n^{-1}\right)$ [Eq. (3)], where τ_m and τ_n are the lifetimes of the corresponding subbands[4] (in Ref. 5, τ_m and τ_n are named momentum relaxation times, but, nevertheless, the relation between j and τ_m, τ_n remains the same). We believe the correct result [see Eqs. (5) and (7) in Ref. 2] to be $j \propto \left(\nu_m^{-1} - \nu_n^{-1}\right)/\Gamma$, where ν_m and ν_n are the *momentum*-relaxation rates, which are, generally, completely different from τ_m^{-1} and τ_n^{-1}, and $\Gamma = \frac{1}{2}\left(\tau_m^{-1} + \tau_n^{-1}\right) + \Gamma_{mn}$ is the *polarization*-relaxation rate with Γ_{mn} as the dephasing contribution.

The difference between the results of Ref. 2 and Refs. 4,5 is essential in both quantitative and qualitative respects. Quantitatively, considering the two above given relations, their relevant parameters are different. In particular, the magnitude of Γ may exceed γ by one order of magnitude or even more due to the dominating contribution of the dephasing term Γ_{mn} (see Ref. 2 for additional discussion). Qualitatively, in our case[2], the momentum relaxation is due to collisions with impurities, which can be mainly elastic, in accord with the original LID.[7] This is advantageous for achieving a large difference $\nu_m^{-1} - \nu_n^{-1}$ without increasing the width Γ, thus obtaining high current j. In contrast, the shortening of the subband lifetime, in particular by phonon emission as suggested in Ref. 4, necessarily causes an increase of Γ and diminishes the current.

The difference $\nu_m - \nu_n$ can be controlled by the characteristics of the quantum well, in particular, by the modulation doping. For instance, in the case[2] of doped barrier regions we have $\nu_n > \nu_m$, while δ-doping of the well center would result in $\nu_n < \nu_m$. The reason for this is that the wave function of the excited subband $|n\rangle$ has a node in the well center and is, therefore, less perturbed by impurities. In contrast, the effect of optical phonons, considered in Ref. 4, always yields $\tau_m^{-1} < \tau_n^{-1}$.

On the ground of the above arguments, we do not agree with the above quoted

statements of Ref. 1.

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